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Visual Search With Embedded Targets

by

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Visual search may be necessary where nontarget objects in the search area compete for attention with the target object (competition situation) or where a target blends with its background (embedded situation). This research is the first direct investigation of parameters of embedded target search situations. The research sought (a) to determine the relationships between measures of visual search performance, peripheral visual acuity, and ratings of discriminability obtained with embedded targets, and (b) to compare competition and embedded search tasks. (Continued)

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Competition tasks used constructed color displays; embedded tasks used five different color and four different textural black-and-white displays. Embedded target discriminability was rated by 28 observers for all five colors and four textures, in three different target locations. Several sets of visual search experiments were carried out. In two experiments using embedded target displays, search times were recorded for the five color targets and the four black-and-white textural targets. In four experiments, with the elements of the color display separated to varying degrees to create competition search tasks, search times were recorded, for a target that differed in size (one experiment) and for two of the color targets (three experiments). Peripheral visual acuity was measured for the color embedded display, the color separated displays, and the black-and-white embedded display.

Search time was inversely proportional to peripheral acuity and to discriminability. Embedded search was easier than competition search. In comparing competition and embedded target search tasks, two opposing effects were noted. As the separation of the background elements increased, the target became harder to discriminate, tending to increase search time, but the number of background elements present within the fixed display area decreased, tending to decrease search time. The order of difficulty of the two color targets used changed in going from the embedded to the competition task.

This report shows that, using complex texture backgrounds, simple relationships exist between visual search time, peripheral visual acuity, and rated discriminability. The technological base research, of interest primarily to research specialists, suggests that further study may lead to the development of predictive procedures for search performance in complex real world tasks (such as air-to-ground target acquisition), and could give us the ability to select and train effective observers for these search tasks.

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VISUAL SEARCH WITH EMBEDDED TARGETS

BRIEF

Requirement:

This study provides the first direct investigation of embedded target search situation parameters. The specific requirements were: (1) to determine the relationships between measures of visual search performance, peripheral visual acuity, and ratings of discriminability obtained with embedded targets and (2) to compare competition and embedded target search tasks.

Procedure:

Embedded target displays were constructed using color and black-and-white textural backgrounds. In a rating study, the discriminability of five color and four black-and-white targets from their backgrounds was rated by 28 observers. A series of visual search experiments was carried out. In two experiments, using the embedded target displays, search times were recorded for the five color targets (with N = 5) and the four black-and-white textural targets (N = 6). In four experiments, with the elements of the color display separated to varying degrees to create competition search tasks, search times were recorded for a target that differed in size (N = 4) and for two color targets (N = 7, 7 and 3 in three experiments). Peripheral visual acuity was measured for the color embedded display (N = 5), the color separated displays (N = 7), and the black-and-white embedded display (N = 4).

Findings:

Proportionality relationships were found between mean search time ($\bar{t}$), peripheral visual acuity (θ), and rated discriminability (D) as follows:

$$\bar{t} \propto \frac{1}{\theta^2}$$

$$\bar{t} \propto \frac{1}{D^2}$$

$$\theta \propto D \ .$$

In comparing competition and embedded target search tasks, two opposing effects were noted. As the separation of the background elements increased, the target became harder to discriminate, tending to increase search time. As separation increased, the number of background elements present within the fixed display area decreased, tending to decrease search time. The order of difficulty of the two color targets used changed in going from the embedded to the competition task.

Utilization of Findings:

Using very complex texture backgrounds, simple relationships were shown to exist between visual search time, peripheral visual acuity, and rated discriminability. This very encouraging finding leads one to expect that further study should lead to the development of predictive procedures for search performance in complex real world tasks (such as air-to-ground target acquisition), and should give us the ability to select and train effective observers for these search tasks.

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VISUAL SEARCH WITH EMBEDDED TARGETS

BACKGROUND

Visual search plays a part in aerial surveillance, aerial reconnaissance, the avoidance of mid-air collisions, missile detection, and air-sea rescue, whether the observer is viewing the environment directly or by means of a sensor display.

Visual search is necessary when, for some reason, a target object cannot be seen immediately. There are several reasons why search may be necessary; the target may be near threshold, it may be very small relative to the search area, it may be obscured by an obstruction, it may be distorted by the optical conditions, or it may be difficult to identify because it is in an unusual orientation. However, the most important reasons for search are (1) that the target may be confused with other nontarget objects that are also within the search area (a competition search situation), and (2) that the target may not emerge perceptually from its immediate background because the patterning of the target and background combine in some way (an embedded target search situation). There has been a considerable amount of research work done on the first of these two situations, but comparatively little on the second one.

Search tasks employing embedded targets have been used in several investigations. However, all of them could have been carried out using tasks based on some other search determinant. In spite of the importance of embedded search situations, and in spite of their prevalence in military and industrial settings, their parameters have not previously been directly investigated.

Cott (1940) dealt with animal camouflage in a systematic way, from a zoological viewpoint. He began the work of elucidating the variables involved when a predator hunts for a camouflaged prey. The principles he derived also apply in situations involving humans.

Cott isolated four principles of camouflage: (1) color resemblance, i.e., the similarity in the color of a target and of the background against which it is placed; (2) obliterative shading, i.e., counter lightening and darkening which aims to diminish the appearance of roundness or relief due to light and shade; (3) disruptive coloration, i.e., a superimposed pattern of contrasted colors and tones serving to blur the outline and break up the surface appearance of the target; and (4) shadow elimination, i.e., the diminution or removal of shadows cast by the target object. In the current study, our interest is in the extent to which the procedures adopted in accordance with these principles are effective.

In studies using competition search tasks, it has been shown that search time and peripheral acuity are inversely proportional to each other (Smith, 1961; Bloomfield & Howarth, 1969; Bloomfield, 1970). Further, visual search performance has been related to the measurable characteristics of the target and nontarget stimuli (Howarth & Bloomfield, 1969). These two relationships can be expressed as follows:

$$\bar{t} \propto \frac{1}{\theta^2} \tag{1}$$

and

$$\bar{t} \propto \frac{1}{(d_B - d_T)^2} \tag{2}$$

where $\bar{t}$ is mean search time; θ is peripheral acuity, and d_B and d_T are the diameters of the background nontargets and the target, respectively.

These experiments were designed in order to ascertain whether similar relationships could be found using complex embedded target situations.

OBJECTIVE

An embedded, or camouflaged, target is one which does not stand out from its immediate background because of the way that its patterning or texture appears to combine with the background structure. The present study was the first study designed specifically to investigate directly some of the parameters of embedded target situations.

The objectives of the study were:

(1) to determine the relationships between measures of visual search performance, peripheral acuity, and ratings of discriminability obtained with embedded targets, and

(2) to compare competition and embedded target search tasks.

METHOD

Cott dealt with situations in which the target covers part of its immediate background, hence his emphasis on relief and shadows. Both of these possible cues to detection were removed in this study by replacing part of the background with a target. The targets used were examples of color resemblance, with the degree of resemblance varied. Our observers were all Ohio State University students with normal vision (some corrected). They were paid at the rate of $2.00 per hour.

Selection of Textures

Two sources of stimulus material were used. The first was commercially available vinyl floor tiles. These were similar to each other in texture, but differed in the range of colors used in their construction. The tiles will be referred to in this report by a single color name for convenience (yellow, white, tan, green, blue, and red).

The second source was provided by Brodatz (1966) in his book of photographic textures. Two sets of textures were selected and presented to seven judges. They judged the similarity of the textures within each set in two ways: (a) simple ranking, (b) magnitude production, i.e., estimating length along a line as a measure of similarity. High correlations were found between the measurements made with the two techniques, between observers, and between repeated measurements obtained from the same observer. For one set of textures, the correlations were 0.94 or greater; for the second set they were at least 0.72. The first of these two sets was selected for use in our subsequent experiments. It consisted of the following textures: oriental straw cloth, woollen cloth, pigskin, beach sand, and expanded mica.

Treatment of Textures

1. Color Displays. The background consisted of one-inch squares cut from the yellow tiles. For the embedded color display, 400 squares were arranged, touching each other, on a 20-inch by 20-inch display. Four tiles were used to construct this display and the original positions of the one-inch squares were retained. An effort was made to match between tiles, and it was very difficult to tell that the display was not made from one single large tile.

For the competition color displays, one-inch squares were again cut from yellow tiles and arranged on the various displays. They were arranged in matrices with equal spacing between the squares.

2. Black-and-White Texture Display. The selected Brodatz photographs were enlarged (magnified three times). A 14-inch by 15-inch portion of the enlargement of the expanded mica texture was cut into one-inch squares and mounted on a 14-inch by 15-inch display.

Rating Procedure

A series of 5-inch by 5-inch-square sections were taken from the color and the black-and-white embedded displays. One section was taken from each quadrant of the displays. Then each section had a target placed in one of three positions relative to it. The target was either two inches from the middle of the right edge of the section, or it replaced the background square in the middle of the right edge of the section, or it replaced the background square in the center of the section.

For the color material, the targets were one-inch squares cut from a white, tan, green, blue, or red vinyl tile. Four examples were chosen of each color. One example from each set of four was used with one of the four color background sections. For the black-and-white material, the targets were one-inch squares cut from the enlarged Brodatz pictures of oriental straw cloth, woollen cloth, pigskin, and beach sand.

A series of photographs was taken. For the color material there were 60 slides (4 sections by 3 positions by 5 targets), and for the black-and-white material there were 48 slides (4 sections by 3 positions by 4 targets).

The 108 slides were arranged in 12 sets of 9 (4 sets each with the target central, in the edge, and separated). The sets were arranged in one of the two orders shown in Table 1 before being presented to a group of judges.

Table 1

Order of Presentation of Sets of Slides for Rating-Discriminability Study

Order	1	2	3	4	5	6	7	8	9	10	11	12
I	C	E	E	C	S	E	S	C	E	C	S	S
II	S	C	E	C	S	S	C	E	E	C	S	E

Key: C - target central, E - target in edge, S - target separated.

Six groups of judges were used. Groups 1, 3, and 6 (containing 4, 6, and 3 judges, respectively) received order I. Groups 2, 4, and 5 (containing 4, 5, and 6 judges, respectively) received order II.

When projected onto a screen, the 5-by-5 sections measured 20 inches by 20 inches, the individual 1-by-1 squares measured 4 inches by 4 inches, and the distance between the background section and the target in the separated condition became 8 inches. The judges sat 9 feet from the screen.

Each slide was projected for 5 seconds with 10 seconds given as a response period. A brief rest period of 3 to 4 minutes was given between each set of 9 slides. The sessions lasted for approximately 55 minutes.

The judges always knew in which position the target would occur. Their task was to gauge the discriminability of the target from the background. They made a mark on a 7-inch line to indicate their judgment. The longer the line (i.e., the further from the left that they bisected the line) the easier the discrimination. Each judgment was recorded on a new page of a prepared booklet. The data is presented as the average of 112 judgments per target per condition (4 replications for 28 observers).

Visual Search

The 1-inch background and target squares were mounted on aluminum sheets. Metallic adhesive tape was stuck to the back of each square of tile or photograph. The display area of the aluminum was painted with grey magnetic paint. The border of the display was painted matt black. The background squares were numbered and mounted magnetically on the display sheets.

The embedded target color display appeared as a 20-inch by 20-inch yellow area by a 2-inch black boundary. The embedded target black-and-white display was a 14-inch by 15-inch texture area with a 5-inch boundary at the sides (4-1/2 inches top and bottom). The competition color displays consisted of a number of regularly arranged equally-spaced yellow squares in a grey background, with a black border. This border was 2 inches wide in Experiments 2(a), (c), and (d) and in one condition in Experiment 2(b). The border width was increased to 4 inches and 7 inches in the two remaining conditions, with reduced search area in Experiment 2(b).

The displays were exposed to the observer by means of a large tachistoscopic arrangement. This is shown in Figure 1. The lighting was provided by the available normal room lighting via the open top of the apparatus. Viewing distance was 74 inches. The display was approximately $15^{\circ}26'$ square at this distance. The observer looked through a narrow slit window at a blank yellow field. The experimenter positioned a target in the display and then the observer pressed a button. The shutter swung around obscuring the blank field and revealing the search display. The observer's task was to locate the target as quickly as possible and then to release the button. Then the shutter swung back obscuring the display, and stopping a timer that had been activated as the shutter opened. The observer was asked to give the approximate location of the target, to check that he had, in fact, seen it, and the experimenter recorded the search time. The observer was always told the search time.

In Experiment 1, five color targets were used. There were 5 blocks of 12 search trials in each 1-hour session. The target color remained constant in each block, although the actual target was varied from trial to trial, being selected from the examples cut for the rating study.

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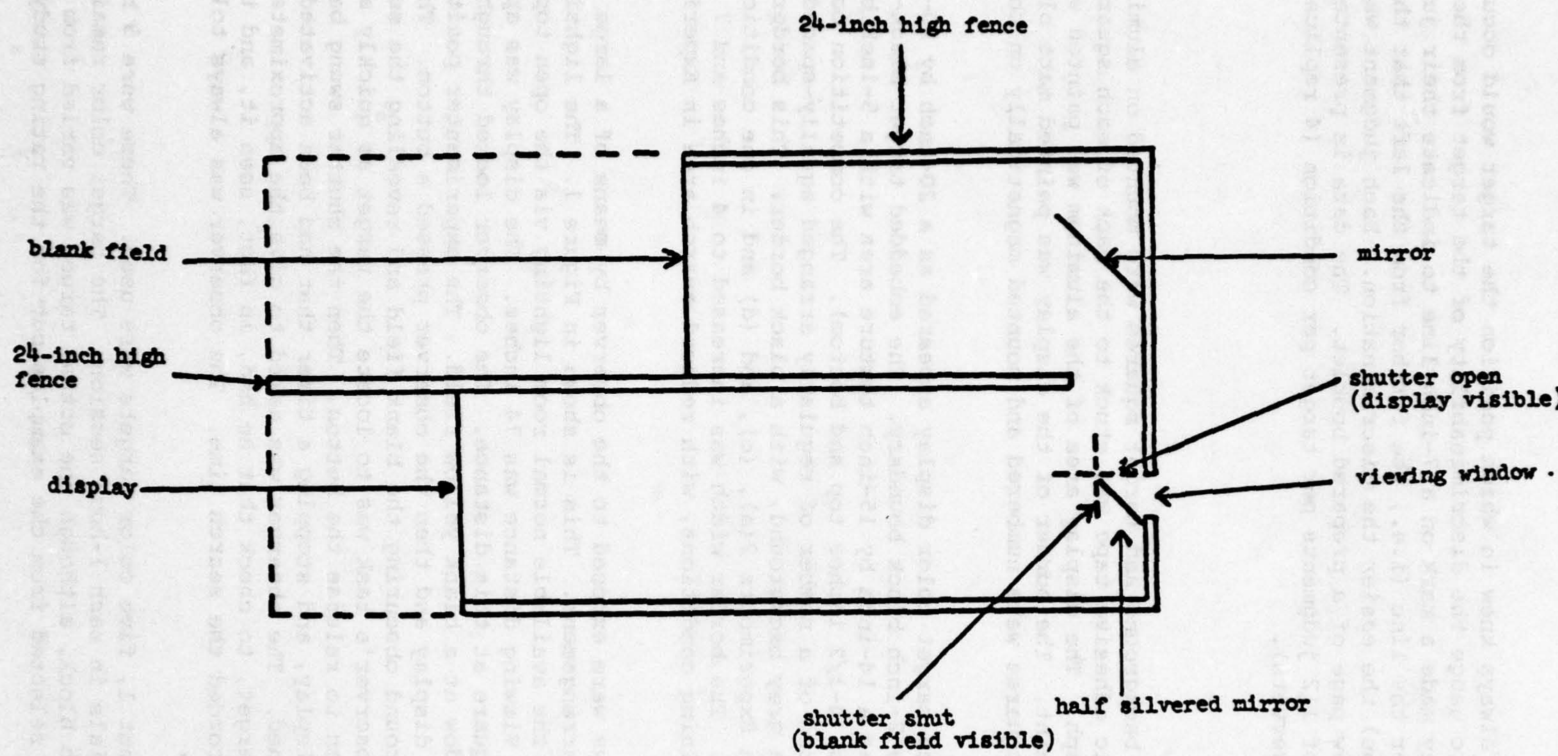

Figure 1. Overhead view of experimental set-up (1/16th of actual size)

Each observer had three 1-hour practice sessions, followed by five 1-hour experimental sessions. A balanced randomized order of presentation of the blocks of trials was used across the experimental sessions. Each session was presented on a separate day. Five observers were used.

In Experiments 2(a) and (b), two color targets were used--the tan and the white. There were three display conditions in these two experiments. In Experiment 2(a) the search area was kept constant at 20 inches by 20 inches. The number of background squares was 400, 256 (arranged in a 16 x 16 grid) and 100 (arranged in a 10 x 10 grid). In Experiment 2(b), the number of nontargets was kept constant at 100, but the display area was varied, being either 10 x 10, 16 x 16, or 20 x 20 square inches.

In each session of Experiments 2(a) and (b) there were 6 blocks of 10 search trials, one for each of the 6 target-display conditions. There were three practice sessions and six experimental sessions for each observer. Seven observers took part in these two experiments, four taking part in Experiment 2(a) first, then 2(b), while three took part in Experiment 2(b) first, then 2(a).

In Experiments 2(c) and (d), there were six display conditions. The display size was always 20 x 20 square inches. The number of background squares present was 36, 100, 169, 256, 324, or 400 (arranged in 6 x 6, 10 x 10, 13 x 13, 16 x 16, 18 x 18, and 20 x 20 matrices). In Experiment 2(c) one observer was tested with the tan target in six experimental sessions, after practice. Then he was tested with the white target. A second observer was tested with the white target and then the tan target. A third observer was tested with the white target only. In Experiment 2(d) the target was of the same color as the background, but was smaller in size, being 11/12-inch square. Four observers were tested in six experimental sessions, after practice.

One observer took part in Experiments 2(a), (b), (c), and (d). Two others took part in Experiments 2(a), (b), and (d).

In Experiment 3, four black-and-white targets were used. They were presented in four blocks of 15 in each 1-hour session. There were four experimental sessions after three practice sessions for each of six observers.

Peripheral Acuity

Peripheral acuity measurements were made using the same apparatus and displays as were used for the visual search experiments. A fixation spot was provided for the observer on the blank field. When the target was positioned the observer pressed the button and the display was briefly exposed. It was revealed for 0.30 second with both embedded target displays. It was exposed for 0.30 and 0.60 second for the competition displays.

On successive exposures, a target item was moved progressively nearer to the fixation point, until the observer was sure he could see it. Then it was moved out successively until he was sure he could not see it. The mean of these two measures was taken as a measure of peripheral acuity.

For the color embedded displays, five observers were tested (the same five who took part in search Experiment 1). The testing took place in four 1-hour sessions. Each session was on a different day. The fixation point was placed in one of two places; it was centered on either the third background square from the top or the third from the bottom of the display in one of the center columns. Three observers had the fixation point at the top for sessions 1 and 4 and at the bottom for sessions 2 and 3. Two observers had the reverse order.

Peripheral acuity determinations were made for four examples of each of the five target colors. Each example was presented with the fixation point up and down. The peripheral acuity data reported are the average of 16 determinations per target per observer (with four examples of each target moved in toward and out from two fixation points).

For the black-and-white texture display, four observers were used. They were four of the six observers who took part in search Experiment 3. One fixation point was used; it was centered on the third background square from the top of the display in the center column. Peripheral acuity determinations were made for five examples of each of the four texture targets. The data reported are the average of 20 determinations per target per observer (with five examples of each target moved in toward and out from the fixation point twice). There were two testing sessions per observer, each lasting for 90 minutes.

For the color competition displays, the peripheral acuity determinations were less clear cut. Seven observers were used with the 20 x 20 square inch search area and 100, 256, or 400 background squares. One of the seven observers took part in search Experiments 2(a), (b), (c), and (d), one in Experiments 2(a) and (b), one in Experiment 2(c), two in Experiment 1, and two were new observers.

For some examples of the white and tan targets, detection was not possible in the 400 background squares condition with exposure times of 0.30 second. Even when exposure time was increased to 0.60 second, the two target types used in these displays were very difficult to detect in the competition displays. It was necessary to choose the more detectable examples of the tan and white targets in order to provide data from all the observers. Even with these targets, three observers (all of whom had taken part in previous search experiments) still had problems. Because of this, an additional condition was added where the observer had to decide whether or not the target was present at the fixation point. The target was presented 50% of the time over 40 trials. The observer controlled exposure time and time became our measure.

The number of testing sessions for the above eight observers varied from three to six. Because unrepresentative tan and white targets were used with these displays, only the general trends of the data are reliable, the detailed results being of much more limited use than those obtained with the two embedded displays.

RESULTS

Rating

Table 2 summarizes the results of the rating discriminability study. Each score is the average of 112 judgments--four replications by each of 28 judges. Low scores indicate targets that are judged to be more difficult to discriminate.

Table 2

Average Discriminability Scores

Target type		Target position: Central	Edge	Separated
Color	white	3.04	3.23	3.41
	tan	4.10	3.59	2.08
	green	5.33	3.78	3.41
	blue	6.02	5.84	4.87
	red	6.39	6.20	5.46
Texture	beach sand	2.43	2.03	2.81
	pigskin	1.90	1.68	2.44
	woollen cloth	3.13	2.19	3.46
	straw cloth	6.12	6.24	6.17

For most targets, the scores for the central and edge positions are similar. With the color display, the exceptions are that the tan and green are judged to be a little more difficult at the edge than in the center. With the black-and-white target, the woollen cloth is judged to be more difficult at the edge.

With the color display, when edge and center scores are compared with the separated scores, all targets except the white are judged to be more difficult to discriminate. The white target is judged to be much the same (possibly a little easier). As a result, for the separated condition, white is no longer judged to be the most difficult. Tan is judged most difficult to discriminate, with green judged as difficult as white.

With the black-and-white display, the straw cloth is judged to be as easy to discriminate in the separated condition as it is in the center and edge conditions. The other three targets are judged to be easier when separated.

Visual Search

1. Embedded Color Display. Table 3 summarizes the results of the embedded target color search experiment. It gives the median search times for each of the five color targets.

Table 3

Median Search Times (Seconds) of Five Observers with Embedded Target Color Displays

Observer	Target Color				
	White	Tan	Green	Blue	Red
R1	3.43	1.71	1.41	0.84	0.67
R2	7.70	1.30	0.78	0.57	0.49
R3	2.83	0.86	0.81	0.68	0.64
R4	3.14	1.40	0.86	0.64	0.48
R5	12.85	2.00	1.28	0.82	0.70
Average	5.99	1.45	1.03	0.71	0.60

Howarth and Bloomfield (1969) related search time in a competition task to the physical characteristics of the target and background stimuli, by means of equation (2). They found that search time was related to the difference between the diameters of their targets and nontargets. We obtained a measure of the difference between the color targets and the yellow background, in which they were embedded, in the rating study. If we substitute D, the rated discriminability of the target from the background, for $(d_B - d_T)$ in equation (2) we get

$$\bar{t} \propto \frac{1}{D^2} \quad . \tag{3}$$

This equation was tested using the average of the median search times of the five observers (from Table 3) and the average of the central and edge discriminability scores (from Table 2) as our measures of $\bar{t}$ and D, respectively. The result of this test is shown in Figure 2. Four of the five data points lie on, or close to, a straight line, fitted by eye, which passes through the origin of the graph. The fifth point, representing the most difficult target (white), clearly does not conform to equation (3).

2. Embedded vs. Competition Displays. (a) Density and number-- Table 4 summarizes the results of the density and number embedded vs. competition study, giving median times for the two color targets in the three density-number conditions.

Table 4

Median Search Times (Seconds) for Seven Observers in Density-Number Experiment 2(a)

Target color		White			Tan		
Number of nontargets		400	256	100	400	256	100
Observer	B1	2.59	4.97	4.88	1.22	8.40	16.54
	B2	4.37	13.22	13.11	2.22	14.23	16.24
	B3	3.20	7.84	6.76	1.11	15.98	17.53
	B4	3.63	5.78	4.24	1.11	8.14	7.44
	E1	2.70	4.27	3.24	0.91	6.17	4.17
	E2	2.04	6.19	3.65	0.82	5.45	4.55
	E3	5.27	7.71	6.32	1.28	8.60	7.63
Average		3.40	7.14	6.03	1.24	9.57	10.59

The relationship between search time and density and number is shown in Figure 3. Mean search time, from Table 4, is plotted against the square root of the number of nontargets. Previous work (summarized by Smith, Kincaid & Semmelroth, 1962, and Bloomfield, 1970) lead us to expect shorter search times with 100 nontargets than with 256 nontargets. This was the case with the white target for all seven observers, and with

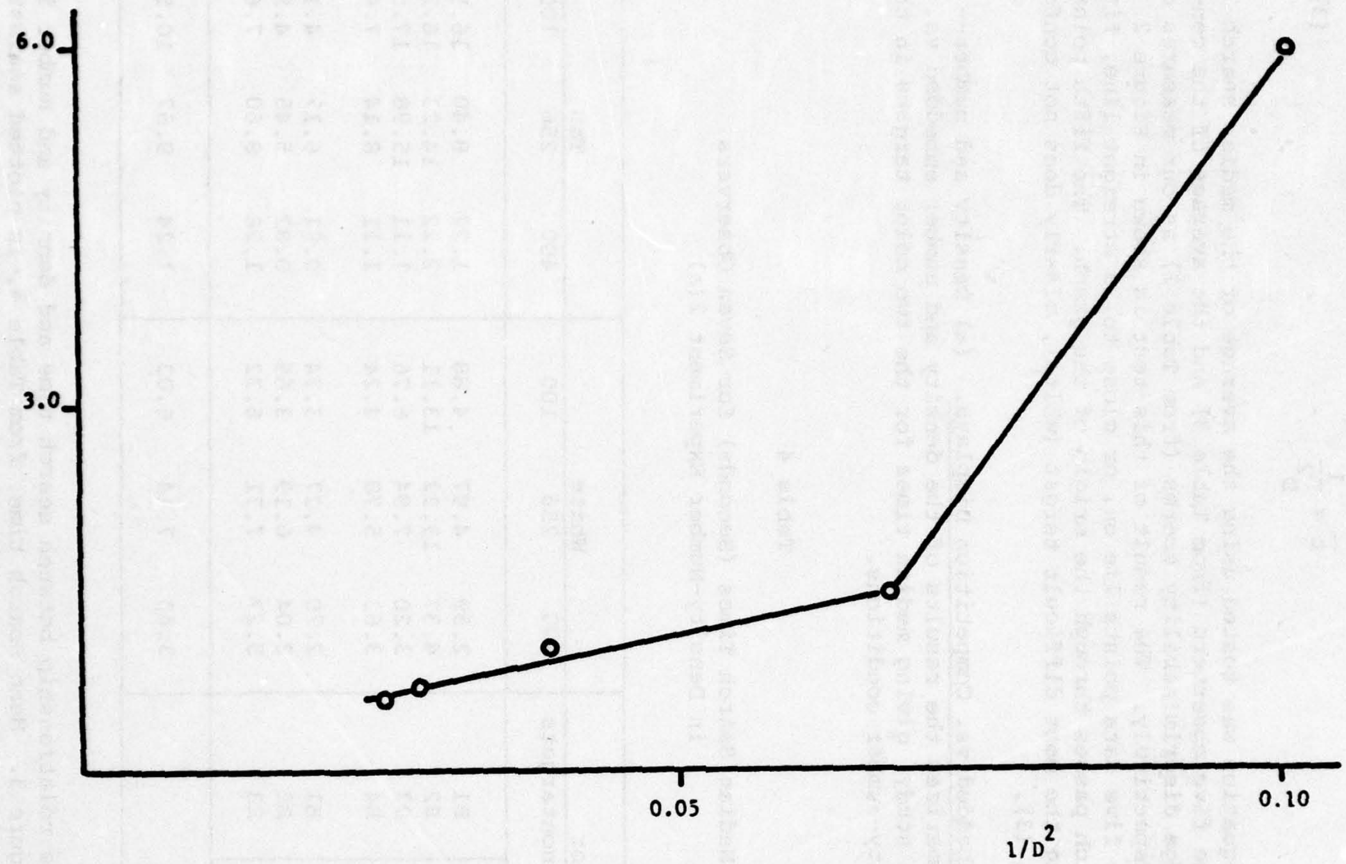

Figure 2. Relationship between mean search time and rated discriminability for five observers searching the embedded target display

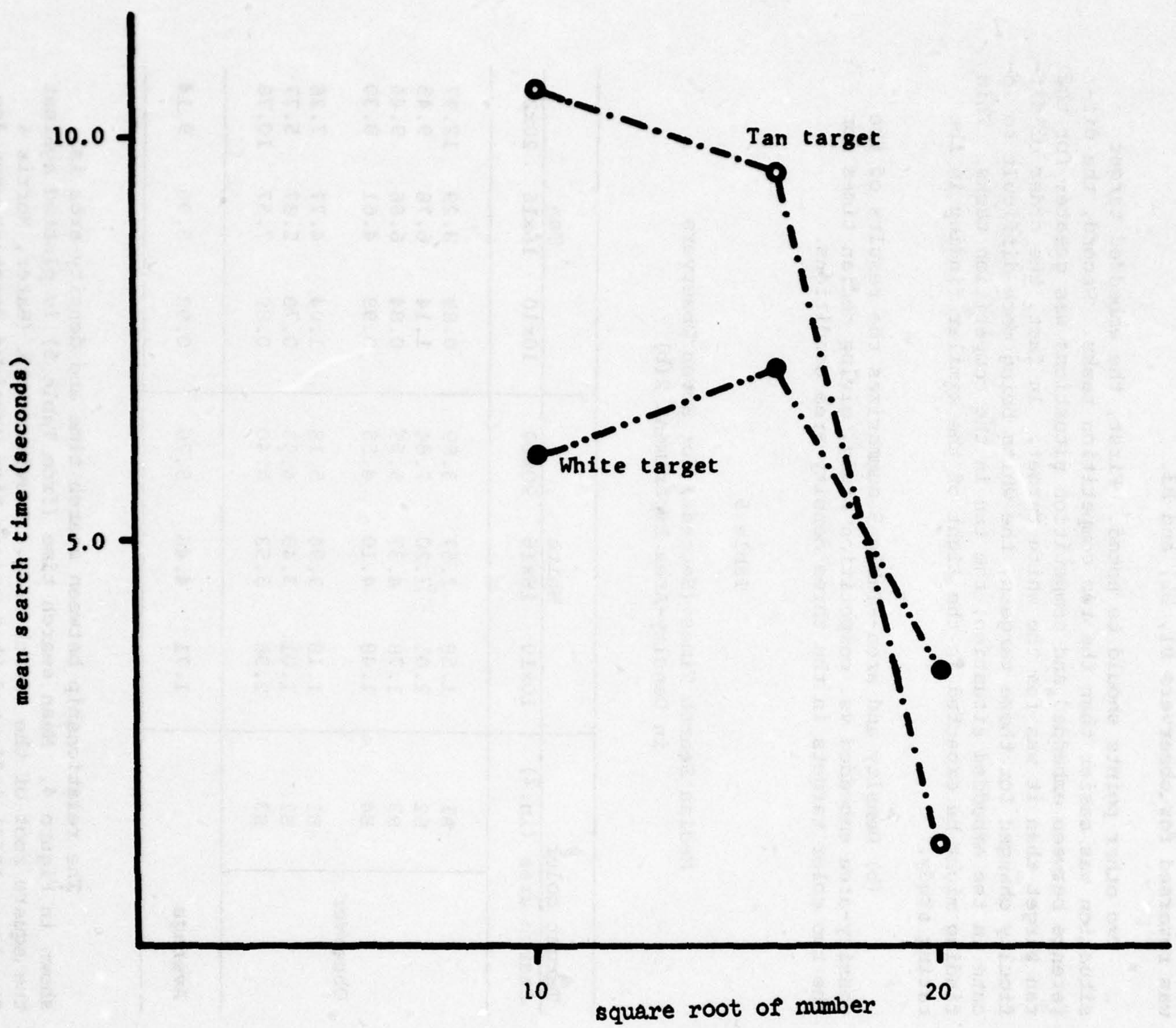

Figure 3. Mean time to locate target as a function of number (and density) of nontargets

the tan target for observers B4, E1, E2, and E3, although the result was reversed for observers B1, B2, and B3.

Two other points should be noted. First, the embedded target situation was easier than the two competition tasks. Second, the difference between embedded and competition situations was greater for the tan target than it was for the white target. In fact, the order of difficulty changed for these targets, the white being more difficult to locate in the embedded situation, the tan in the competition tasks. This finding might be expected in the light of the similar finding in the rating study.

(b) Density and area--Table 5 summarizes the results of the density-area embedded vs. competition study, giving median times for the two color targets in the three density-area conditions.

Table 5

Median Search Times (Seconds) for Seven Observers in Density-Area Experiment 2(b)

Target color		White			Tan		
Search area (in.^{2})		10x10	16x16	20x20	10x10	16x16	20x20
Observer	B1	1.58	2.57	3.89	0.89	8.29	12.97
	B2	2.01	7.20	7.84	1.14	6.78	9.45
	B3	1.78	4.37	5.55	0.84	6.86	9.44
	B4	1.48	4.10	4.55	0.98	4.61	8.30
	E1	1.18	3.94	5.18	1.04	4.77	7.26
	E2	1.01	3.49	4.93	0.70	2.87	5.77
	E3	2.96	5.53	8.40	0.89	7.57	10.78
Average		1.71	4.46	5.76	0.93	5.96	9.14

The relationship between search time and density-area is shown in Figure 4. Mean search time (from Table 5) is plotted against the square root of the search area. Previous work (Baker, Morris & Steedman, 1960) indicated that search time remained constant when density was varied by reducing the search area, while holding number constant. Here search time was found to increase with area. Again, the order of difficulty of the two targets changed as we went from the embedded to the competition situations.

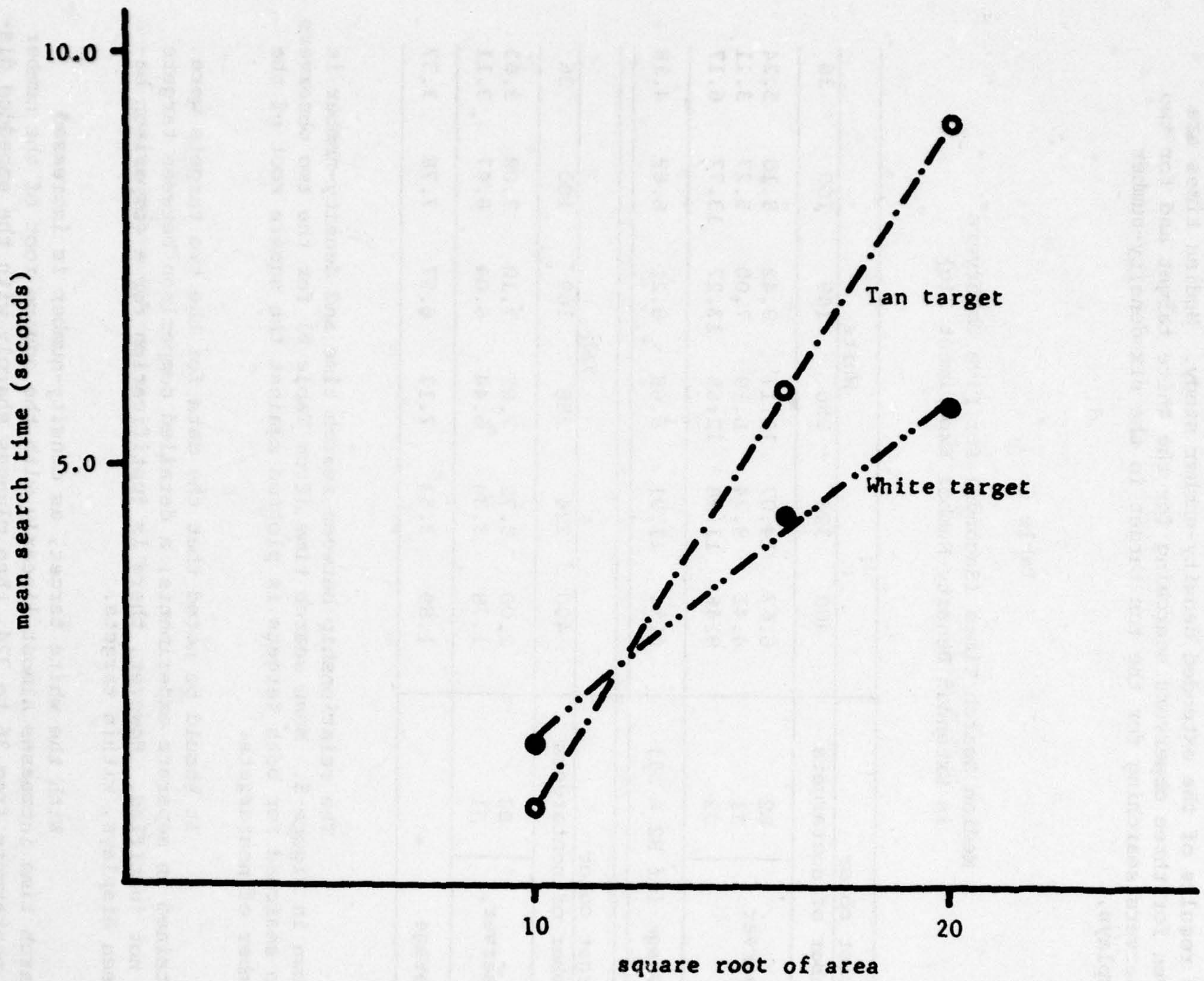

Figure 4. Mean search time as a function of search area

(c) Extended density and number study--Table 6 summarizes the results of the extended density-number study. Median times are given for three observers searching for the white target and for two observers searching for the tan target in the six density-number displays.

Table 6

Median Search Times (Seconds) for Five Observers in Extended Density-Number Experiment 2(c)

Target color		White					
Number of nontargets		400	324	256	169	100	36
Observer	B2	6.67	14.07	11.17	9.42	8.10	5.24
	J1	4.41	9.74	6.19	7.00	5.27	3.11
	J2	8.46	11.98	12.65	13.27	13.77	6.17
Average (of B2 & J1)		5.54	11.91	8.68	8.21	6.69	4.18
Target color		Tan					
Number of nontargets		400	324	256	169	100	36
Observer	B2	2.00	3.72	7.82	7.10	7.08	3.63
	J1	1.78	3.34	6.44	6.04	8.47	3.11
Average		1.89	3.53	7.13	6.57	7.78	3.37

The relationship between search time and density-number is shown in Figure 5. Mean search time (from Table 6) for the two observers who searched for both targets is plotted against the square root of the number of nontargets.

It should be noted that the data for the two targets were obtained in separate experiments; a detailed comparison between targets is not justified. However, there is justification for a comparison between displays, within targets.

With the white target, as density-number is increased search time increases almost linearly with the square root of the number of nontargets from 36 to 324, then plunges sharply with the embedded display with 400 stimuli. The sharp peak did not appear in Experiment 2(a), which omitted the 324 condition. With the tan target, there is an increase from 36 to 100 nontargets, a plateau from 100 to 256, then a decrease to 324 and 400. The 324 nontarget display produced very similar search times to the embedded display for this target.

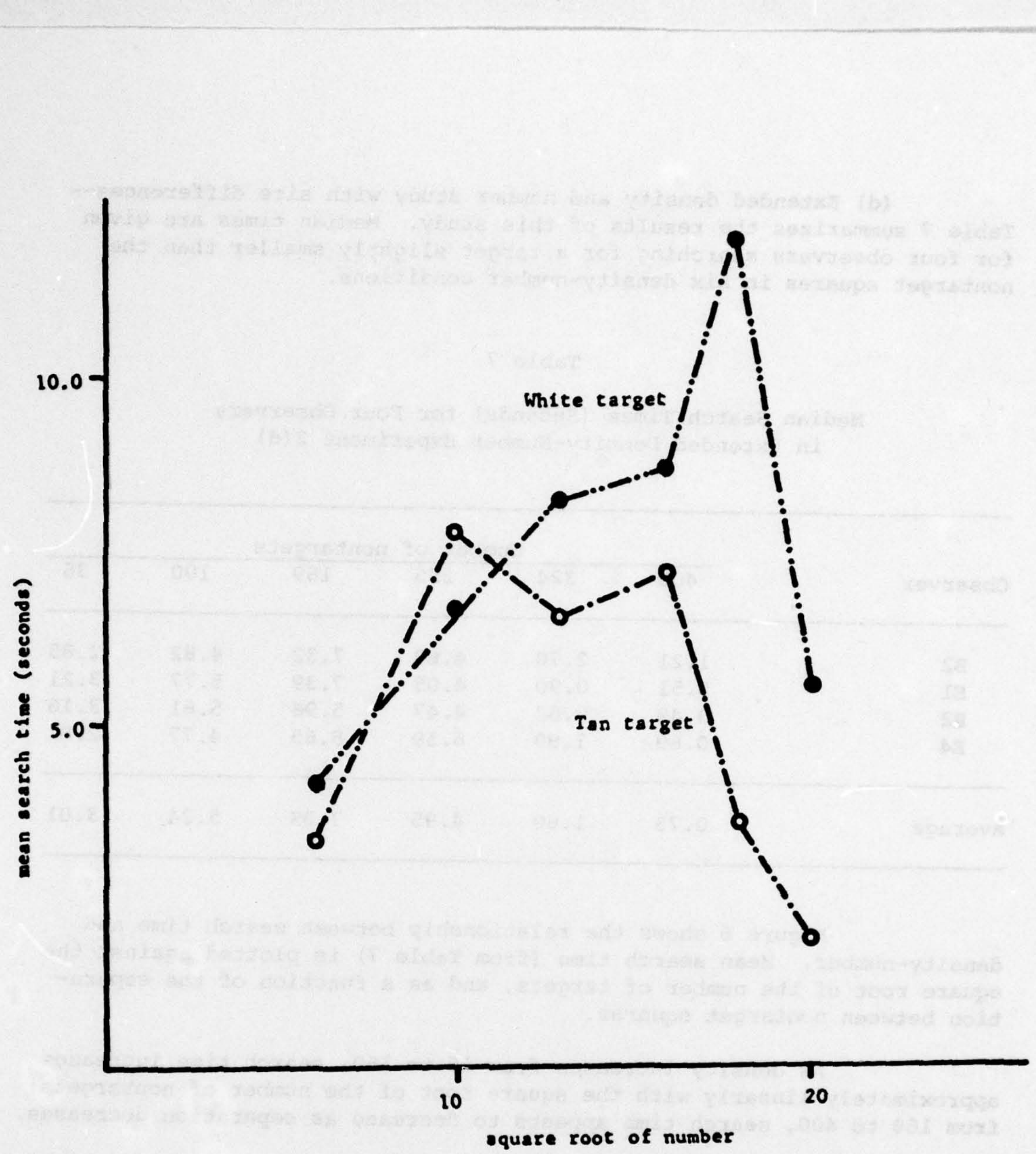

Figure 5. Mean time to locate target as a function of number (and density) of nontargets

(d) Extended density and number study with size differences--Table 7 summarizes the results of this study. Median times are given for four observers searching for a target slightly smaller than the nontarget squares in six density-number conditions.

Table 7

Median Search Times (Seconds) for Four Observers in Extended Density-Number Experiment 2(d)

Observer	Number of nontargets					
	400	324	256	169	100	36
B2	1.21	2.70	4.68	7.32	4.82	2.85
E1	0.51	0.90	4.05	7.39	5.77	3.21
E2	0.49	0.82	4.47	5.96	5.61	3.16
E4	0.69	1.99	6.59	8.65	4.77	2.81
Average	0.73	1.60	4.95	7.33	5.24	3.01

Figure 6 shows the relationship between search time and density-number. Mean search time (from Table 7) is plotted against the square root of the number of targets, and as a function of the separation between nontarget squares.

As density increases from 36 to 169, search time increases approximately linearly with the square root of the number of nontargets; from 169 to 400, search time appears to decrease as separation decreases.

3. Embedded Texture Display. Table 8 summarizes the data obtained using the black-and-white embedded target texture display. Medians are presented for six observers searching for four targets that varied in texture from the background.

Using the rated discriminability scores of the texture targets (from Table 2) we again tested equation (3). Figure 7 shows the results of this test. A straight line has been fitted, by eye, and the relationship appears to be approximately linear. Also, from the discriminability data one would expect the mean time for the woollen cloth target to be shorter than that for beach sand, and not longer.

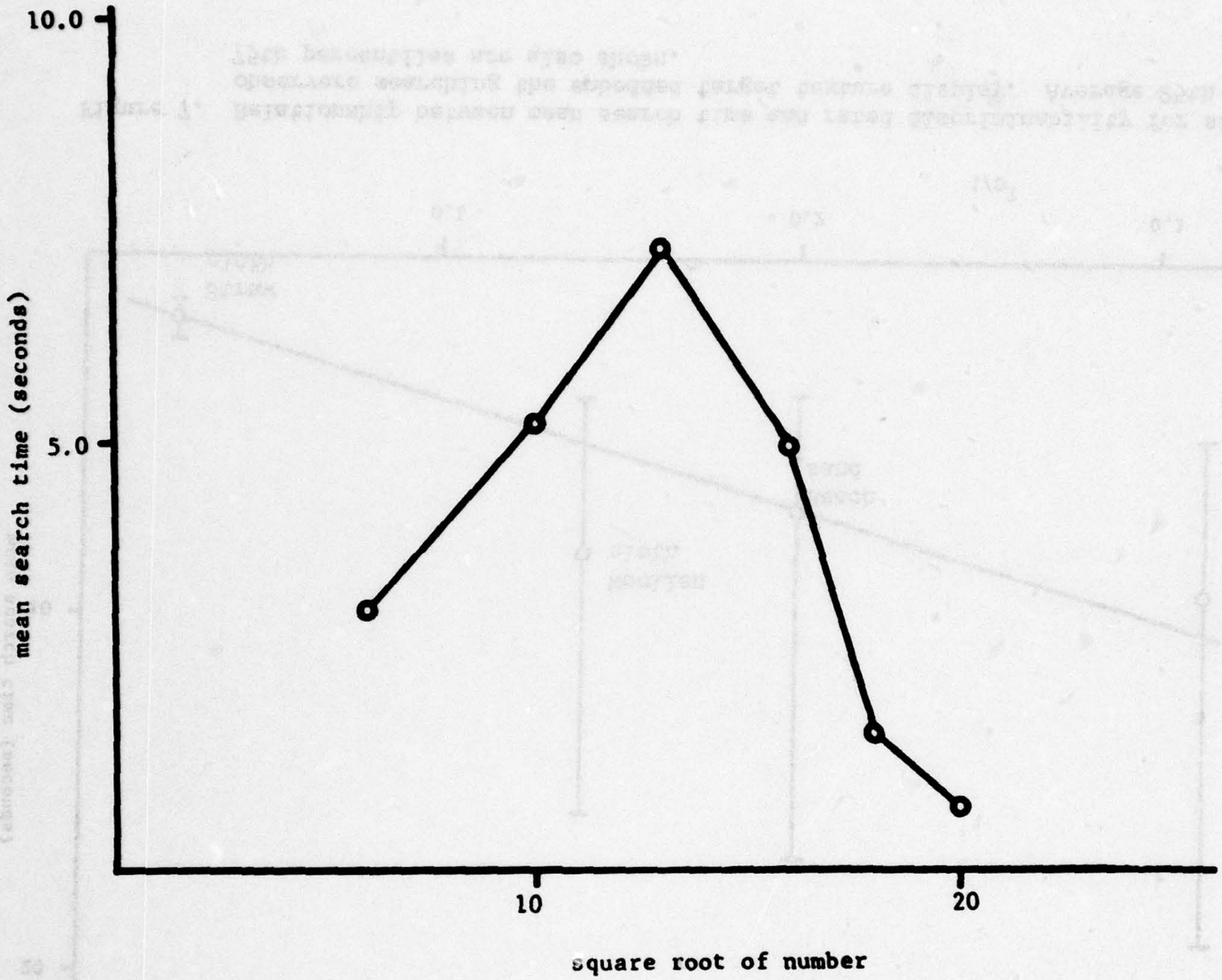

Figure 6. Mean time to locate a target differing in size from the nontargets as a function of the number (and density) of nontargets

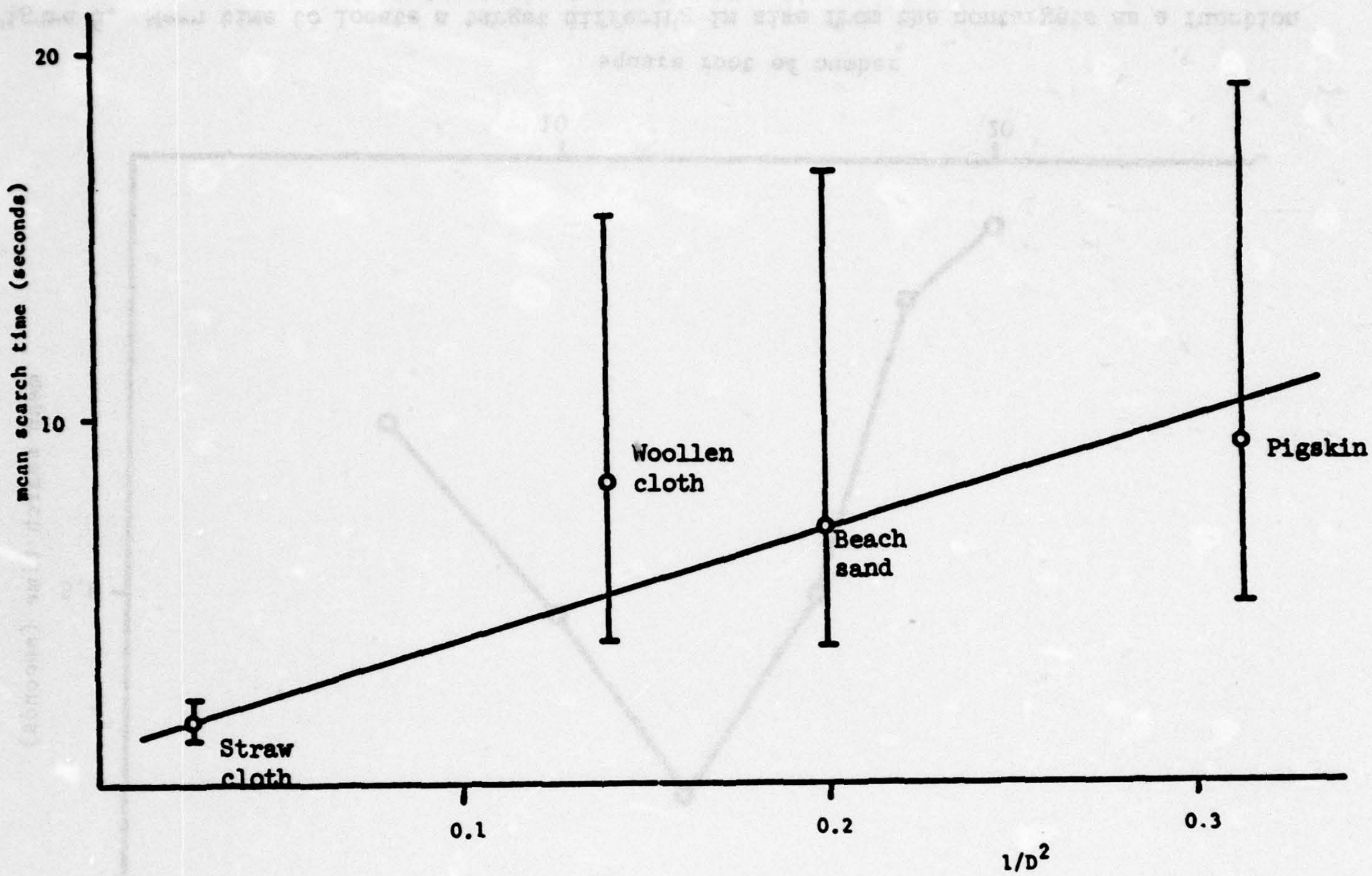

Figure 7. Relationship between mean search time and rated discriminability for six observers searching the embedded target texture display. Average 25th and 75th percentiles are also shown.

Table 8

Median Search Times (Seconds) of Six Observers with Embedded Target Texture Displays Experiment 3

Observer	Target texture			
	Beach sand	Pigskin	Woollen cloth	Straw cloth
M1	3.40	4.01	3.94	1.28
M2	2.76	3.77	3.88	1.29
M3	11.13	9.40	7.12	2.19
M4	12.93	21.86	19.18	1.91
M5	7.67	5.99	5.94	1.66
M6	4.45	10.67	9.51	1.58
Average	7.06	9.28	8.26	1.65

Peripheral Acuity

1. Embedded Color Display. The results of the peripheral acuity measurements made with the embedded color display are summarized in Table 9. This table presents the mean distance away from the fixation point at which each target could be detected, in terms of visual angle. No values were obtained for the red target because the detection threshold was greater than the distance from the fixation point to the edge of the display.

Howarth and Bloomfield (1969) arrived at equation (2) via an equation relating peripheral visual acuity to the diameter difference of their target and nontarget discs:

$$d_B - d_T = m\theta \qquad (4)$$

where d_B and d_T are the diameters of the background and target stimuli, respectively. θ is peripheral acuity and m is a constant. Replacing (d_B-d_T) in this equation by D, the rated discriminability of the embedded target from the background, we obtain:

$$D = m\theta \qquad (5)$$

Figure 8 illustrates this equation, using values of D and θ from Tables 2 and 9, respectively. The equation provides a good description of the relationship for the four targets for which peripheral acuity measures could be made.

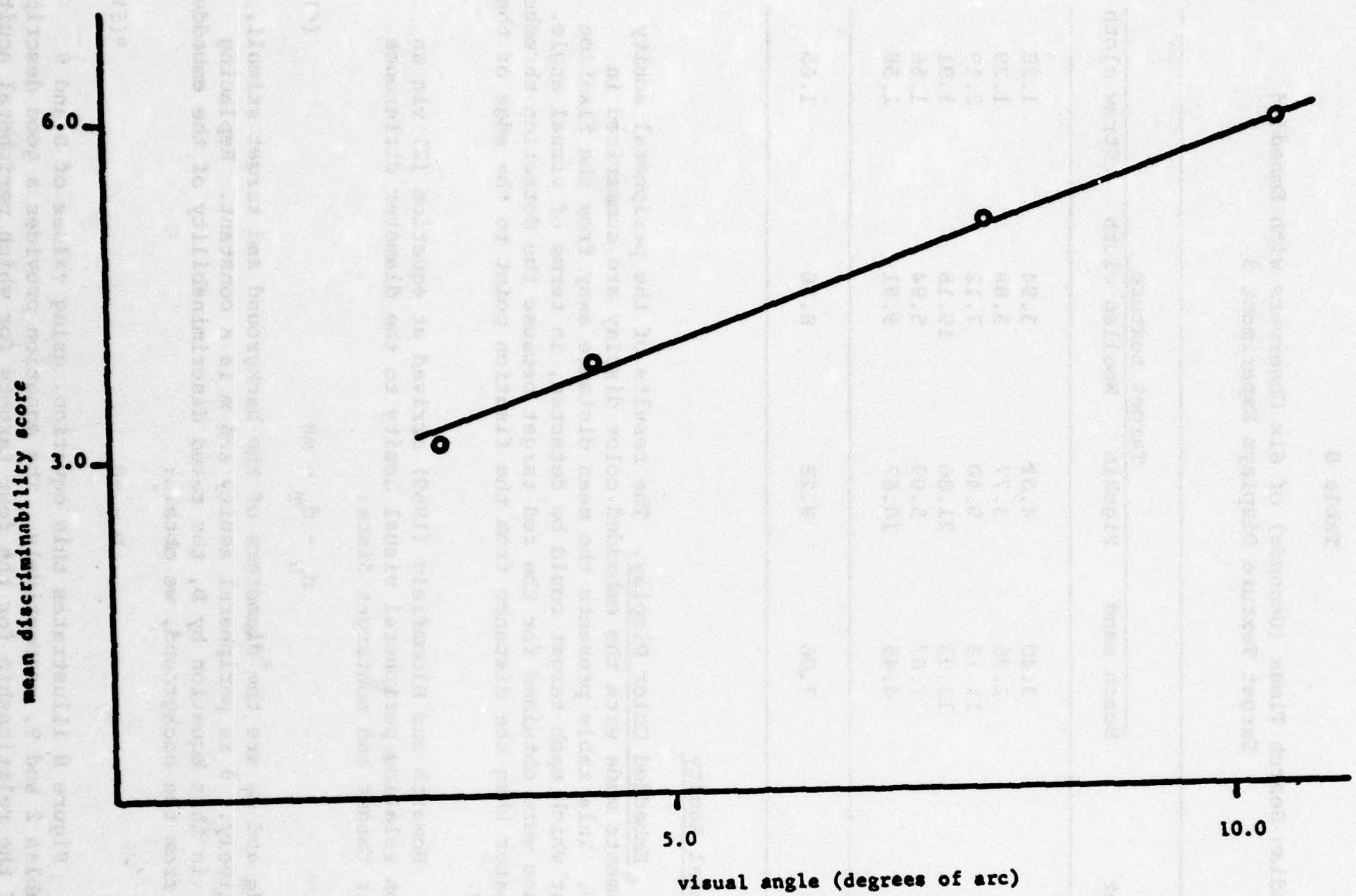

Figure 8. Mean discriminability score plotted against the angular eccentricity at which the target can be detected in the embedded color display

Table 9

Peripheral Acuity Measured by Mean Visual Angle (Minutes of Arc) at Which Embedded Color Targets Could Be Detected

Observer	Target color: White	Tan	Green	Blue	Red
R1	231.5	407.4	597.3	759.3	-
R2	138.9	208.4	634.3	782.5	-
R3	157.4	222.2	365.8	541.7	-
R4	208.4	199.1	384.3	546.3	-
R5	138.9	175.9	361.1	615.8	-
Average	175.0	242.6	468.6	649.1	-

2. Embedded vs. Competition Displays. As stated in the METHOD section, only the general trends of the acuity data obtained with the competition displays are reliable. For the white target, whether acuity was measured peripherally with a 0.3 or 0.6 second exposure, or foveally in terms of detection time, the order of difficulty was the same. The 256 display was hardest, the 400 easiest, with the 100 display in between. This ordering agrees with that obtained for visual search performance with this target in Experiments 2(a) (Table 4) and 2(c) (Table 6).

For the tan target, for all three acuity measures, it was more difficult to discriminate the target in the 256 display than in the 100 display. With the 0.3 second exposure and detection time data the 400 display was intermediate; while with the 0.6 second exposure it was easier. The search data of Experiments 2(a) and 2(c) suggested that the order should have been, from easiest to hardest, 400 - 256 - 100.

3. Embedded Texture Display. The results of the peripheral acuity measurements made with the embedded texture display are summarized in Table 10. The extent into the periphery that the four texture targets could be seen is reported in terms of visual angle.

Equation (5) was tested for the texture display in the same way as the color display. Figure 9 illustrates this test. Again, the equation provides a good description of the relationship between rated discriminability and peripheral acuity.

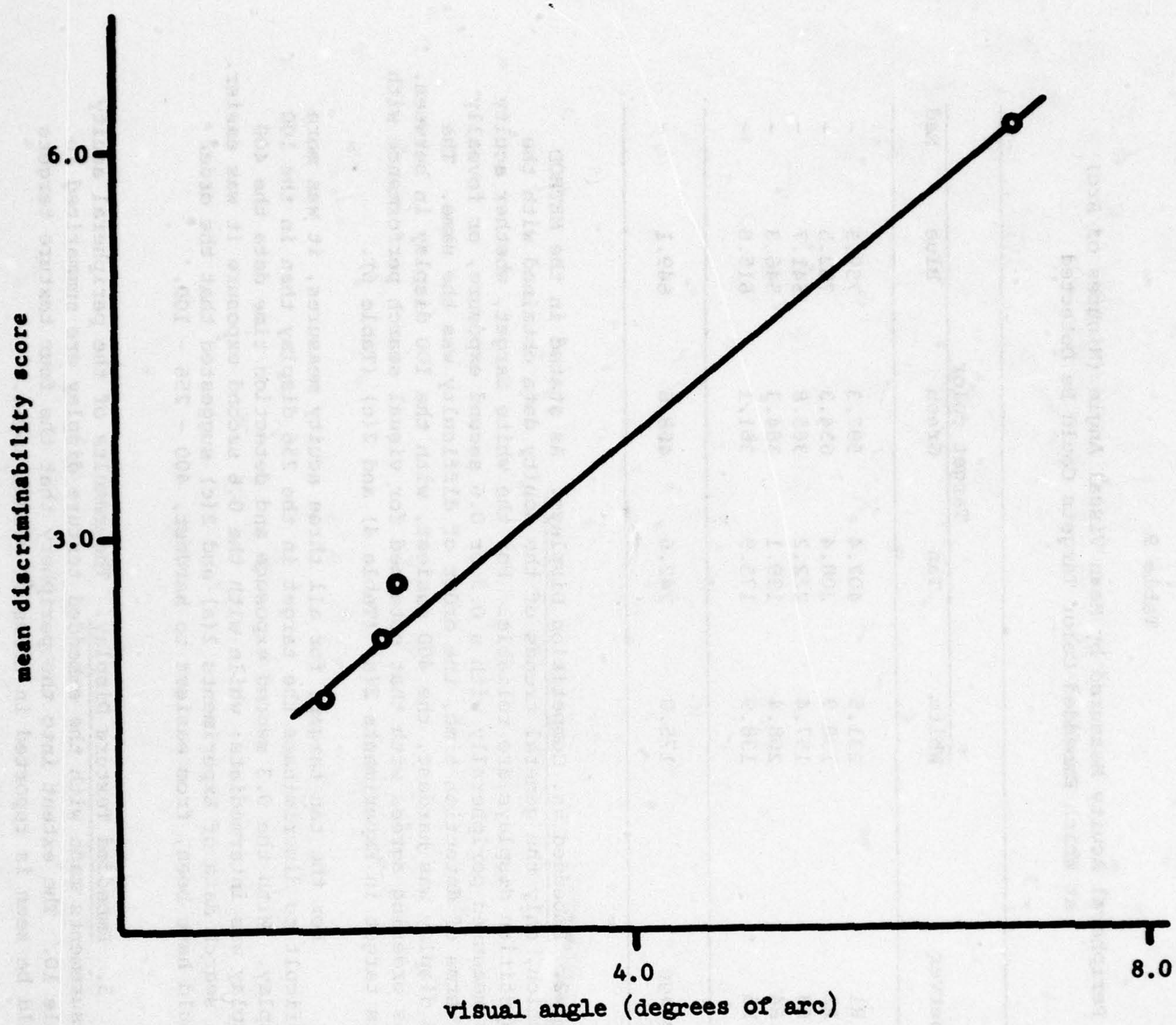

Figure 9. Mean discriminability score plotted against the angular eccentricity at which the target can be detected in the embedded texture display

Table 10

Peripheral Acuity Measured by Mean Visual Angle (Minutes of Arc) at Which Embedded Texture Targets Could Be Detected

	Target texture			
Observer	Beach sand	Pigskin	Woollen cloth	Straw cloth
M1	115.8	71.8	108.8	365.8
M2	136.6	99.5	132.0	388.9
M3	111.1	94.9	88.0	386.6
M5	127.3	120.4	199.1	539.4
Average	122.7	96.7	132.0	420.2

DISCUSSION

The objectives of this study were:

(1) To determine the relationships between measures of visual search performance, peripheral acuity, and ratings of discriminability obtained with embedded targets.

(2) To compare competition and embedded search tasks.

With a competition search task, search time can be related to peripheral acuity and to the measurable characteristics of the target and nontarget stimuli by means of the following two equations:

$$\bar{t} \propto \frac{1}{\theta^2} \quad (1)$$

and

$$\bar{t} \propto \frac{1}{(d_B - d_T)^2} \quad (2)$$

where $\bar{t}$ is mean search time, θ is peripheral acuity, and d_B and d_T are the diameters of the background nontargets and of the target, respectively.

Using embedded targets, similar relationships were found. The $(d_B - d_T)$ term in equation (2) was replaced with D, the rated discriminability of the targets when embedded in the background, to obtain:

$$\bar{t} \propto \frac{1}{D^2} \quad (3)$$

Figures 2 and 7 show this relationship for the average of five observers with the color display and of six observers with the texture display, respectively. Equation (3) can be seen to have value in providing a simplified description of the data, obtained using the color display, though there are departures from the equation, particularly with the white target in the embedded display. It is of less value for the texture display.

Figures 8 and 9 show that

$$D \propto \theta \qquad (6)$$

for both the color and texture embedded target displays, and, from equations (3) and (6), we can derive the relation

$$\bar{t} \propto \frac{1}{\theta^2} \qquad (7)$$

The relationships between search time, peripheral acuity, and rated discriminability can be summarized by equations (3), (6), and (7).

In Experiments 2(a) through 2(d), competition and embedded target situations were compared. Table 11 gives the average median search times for these four experiments. Two distinct competition conditions were used, varying density-number and density-area. Bloomfield (1970) showed that mean search time was proportional to the square root of the number of nontargets present, when density and number were varied together. This relationship was not apparent in Experiment 2(a), but it did emerge to varying extents in Experiments 2(c) and 2(d).

In Experiment 2(b), density was varied inversely with area. Previous work suggests that search time should remain constant when this is done. However, our study found that search time increased with area. A tentative explanation of our seemingly contradictory findings may be revealed when we note that in all four studies, Experiments 2(a) through 2(d), carried out here, we have included the limiting density condition, in which the entire search area is covered with nontargets. No previous density-number-area studies have approached this limit. Clearly, a second variable, the extent to which nontargets are separated, affects search time. With an equivalent range in the number of nontargets, Experiments 2(c) and 2(d), the contradictory effects of number of nontargets and separation of nontargets are seen to have varying effects. The effect with the white target was very abrupt in Experiment 2(c). The square root relationship of search time and number of nontargets fits the data for all five density-competition displays, and only dips for the embedded target condition. With the size difference target in Experiment 2(d), the square root relationship holds for three density competition displays, then the effect of separation takes over. With the tan target in Experiment 2(c) the curve is U-shaped. At first, time increases with density, then reaches

Table 11

Average Median Search Times (Seconds) for Experiments 2(a) - 2(d)

Experiment	Target (color or size)	Search area	Number of nontargets 400	324	256	169	100	36
2(a)	White	20x20	3.40	----	7.14	----	6.03	----
	Tan	20x20	1.24	----	9.57	----	10.59	----
2(b)	White	20x20	----	----	----	----	5.76	----
		16x16	----	----	----	----	4.46	----
		10x10	----	----	----	----	1.71	----
	Tan	20x20	----	----	----	----	9.14	----
		16x16	----	----	----	----	5.96	----
		10x10	----	----	----	----	0.93	----
2(c)	White	20x20	5.54	11.91	8.68	8.21	6.69	4.18
	Tan	20x20	1.89	3.53	7.13	6.57	7.78	3.37
2(d)	Size 11/12" square	20x20	0.73	1.60	4.95	7.33	5.24	3.01

a plateau and remains constant, with density and separation effects seemingly balanced. Finally, it decreases as the limiting density condition is approached.

In addition to the effects of density and separation, it should be noted that the relative discriminability of the white and tan targets changes as separation increases. This reversal can be seen in the data of the rated discriminability study as well as in the search experiments.

CONCLUSIONS

Using very complex texture backgrounds, simple relationships were shown to exist between visual search time, peripheral visual acuity, and rated discriminability. This finding is very encouraging. Further study should lead to the development of predictive procedures for search performance in complex real world search tasks.

The differences observed between observers suggest that a full scale study could profitably be launched to investigate the selection and training of observers. This would enable improvements to be made in the selection and/or training procedures for visual search and target acquisition tasks.

REFERENCES

Baker, C. A., Morris, D. F., & Steedman, W. C. (1960). Target recogni- in complex displays. Human Factors, 2, 51.

Bloomfield, J. R. (1970). Visual search. Ph.D. Dissertation, University of Nottingham.

Bloomfield, J. R. & Howarth, C. I. (1969). Testing visual search theory. In: Leibowitz, H. W. (ed). Image Evaluation, Proceedings of NATO Advisory Group on Human Factors, Munich, 203-214.

Brodatz, P. (1966). Textures, Dover, New York.

Cott, H. B. (1940). Adaptive Coloration in Animals, Methuen, London.

Howarth, C. I. & Bloomfield, J. R. (1969). A rational equation for predicting search times in simple inspection tasks. Psychonomic Science, 17, 226-227.

Smith, S. W. (1961). Visual search time and peripheral discriminability. Journal of the Optical Society of America, 51, 1462(A).

Smith, S. W., Kincaid, W. M., & Semmelroth, C. (1962). Speed of visual target detection as a function of the density of confusion elements. Memorandum 2900-235-R. Institute of Science and Technology, University of Michigan.